

Wheel Slip Measurement in 4WD Tractor Based on LABVIEW

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Abstract

A slip measurement system was developed for agricultural 4WD tractors based on LabVIEW Software. Firstly, the principle of slip calculation was discussed. After that, the operating principle of this system was introduced, especially in assembly methods of primary sensor, hardware and software of the slip measurement system. Finally, the accuracy of this system and the slip characteristics were analyzed by some experiments. The results showed that error of this system was around 1.5%-2.7% which met the requirements of the slip measurement system. It was found that the slip increased with the depth of tillage.

Keywords

Tractor; Slip measurement; Encoder; Radar; LabVIEW

Introduction

To measure the slip of tractor, driving wheel speed and the body speed should be calculated at first. Between them, the driving wheel speed is generally easier to be measured; therefore, the key point is how to obtain the body speed of tractor accurately. For a 2WD tractor, the speed of tractor can be obtained from the rotating speed of non-driving wheels [Raheman and Jha (2007); Pranav (2010)]. In their measurement, encoder was used to measure the rotating speed. The encoder is an accurate speed measurement device which has been widely used in many tests. For a 4WD tractor, without a non-driving wheel, the speed can't be obtained by the above method, so the measurement needs new speed measuring device. There are three common speed measurement instruments: Fifth wheel instrument, Radar, GPS.

Some researchers measure the speed by means of the fifth wheel instrument which has two major forms: Contact fifth wheel instrument, Non-contact fifth wheel instrument. Contact fifth wheel instrument is only suitable for a particular condition, but not for real-time measuring in all kinds of conditions. Non-contact fifth wheel instrument, also behaves poor when the speed is low, and it has complicated inner structure and poor

environment adaptability.

Some researchers choose GPS. Keskina and Say (2006) found that low-cost GPS receivers can be confidently used to measure the ground speed in agricultural machinery operations. Zhongming and Fang (2009) developed a GPS speed sensor characterized with low-cost, high accuracy and a good performance of anti-jamming and easiness to upgrade and expand. However, GPS requires good weather, and the results are inaccurate when the speed is low.

This study chooses radar-ground speed sensor with such advantages as easy installation, true view of ground surface which would be a good foundation for accurate speed measurement. Many foreign commercial intelligence equipments in agricultural prefer to use this method because it is based on the principle of Doppler shift, another related literature also believe its high precision of speed measurement. Reed and Turner (1993) described a method of obtaining accurate slip readings on a tractor through using two radar guns. Tsuha (1982) carried out radar ground speed measurement for Agricultural Vehicles.

In recent years, many researchers have put their emphasize on developing an accurate on slip measurement [Lyne, P.W., Meiring (1977); Bin and Qun (1997); Collins (1980); Paulsen and Elliott (1973); Zoerb and Popoff (1967)]. Unfortunately, the chip they were all adopted gave them a bad display interface, so that they cannot get the data quickly. In this measurement, LabVIEW and DAQ (data acquisition system) were used to acquire sensor signal and display the most essential information in real time. Li (2008) and Jinming (2010) put forward the measurement method of speed based on LabVIEW and DAQ.

The Principle of Slip Calculation

According to the original definition of the wheel slip:

$$S = 1 - \frac{v}{\omega r} \quad (1)$$

Where S is wheel slip, ω is wheel angular velocity, r is wheel dynamic radius and v is vehicle translational velocity which is got from radar-ground speed sensor.

Rotate speed n is got from encoder can be used to express ω , and the formula becomes:

$$S = 1 - \frac{v}{\frac{2\pi n}{60} r} \quad (2)$$

For four-wheel drive tractor, when it operates, the front axle wheel slip is not equal to the rear axle wheel slip, because there are different load conditions, and the tire size, the tire structure, and the instantaneous soil conditions are various, too. At the same time, due to the existence of differential soil conditions of operation surface, the slip of the left and right wheel at the same axle will be different. In order to know the overall slip of tractors, four tires' slip should be obtained firstly, and then the mean which is the tractor's overall slip can be calculated.

In order to test the accuracy of this measurement, actual slip S_a should be known. While measuring slip by sensor, the real running speed can be calculated according to the actual traveled distance and the time, and further, its slip S_c can be calculated by Eq.(3) based on each wheel's rotate speed n . Finally, the error between S and S_a can be calculated. Essentially, encoder has a good accuracy, so the measurement is a verification of radar-ground speed sensor's accuracy. It is found that the precise of radar affect the accuracy of the system directly.

$$S_a = 1 - \frac{v_a}{\frac{2\pi n}{60} r} \quad (3)$$

Where, V_a is actual running speed of the tractor, m/s, n is rotate speed of the wheel, r/s.

Development of Slip Measurement System

This system contains four encoders, one radar-ground speed sensor, one ADVENTURE PCI-1780 DAQ(Data Acquisition) card, one power supply, and Industrial Personal Computer, etc.. The structure of this system is shown on Fig. 1. The operating principle of this slip measurement system will be explained in the following content.

When the system starts, encoder and radar will send their pulse signals to DAQ card, and the card handles these signals and then send them to the computer through PCI-bus. Then the LabVIEW program in the

computer can first acquire the data, and then calculate, display, finally record these data. At last, these slip data can be interpreted as the changing time. These data can test the accuracy of the system and analyze the characteristics of tractor slip further.

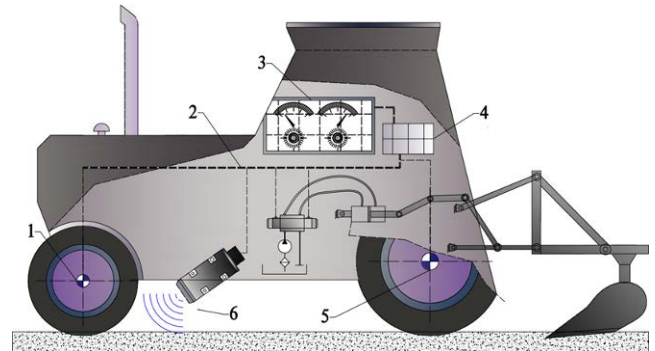


FIG. 1 STRUCTURE OF SLIP MEASUREMENT SYSTEM

1 and 5 – encoders; 2 – cable; 3 – pc and labview interface; 4 – daq card; 6 – radar-ground speed sensor

Working Principle Of Sensor

1) Radar-Ground Speed Sensor

The principle of Radar-ground speed sensor is based on Doppler Effect (moving object has a frequency shift effect of the received electromagnetic wave). Radar-ground speed sensor can catch the quantity of this frequency shift which is used to calculate its moving speed.

According to the Doppler principle:

$$f_d = \frac{2}{\lambda} \cdot V_r \quad (4)$$

Where, f_d is the quantity of Doppler frequency shift, λ is the wavelength of the radar transmitting wave, V_r is the radial velocity of radar relative to the ground.

As a result:

$$V_r = \frac{1}{2} f_d \cdot \lambda \quad (5)$$

$$\text{And } \lambda = \frac{1}{f_s} \cdot c,$$

Where f_s is the radar transmitting frequency, c is the speed of light, 3×10^8 m/s, so Eq.(5) can be transformed to:

$$V_r = \frac{1}{2} f_d \cdot \frac{1}{f_s} \cdot c = \frac{1}{2} \cdot c \cdot \frac{f_d}{f_s} \quad (6)$$

V_r means the speed on the radar wave direction, if the radar is horizontal, then V_r is the speed on the forward direction. If the radar has a rake angle α , the above formula still represents the speed on the

radar direction, but the speed on the forward direction is related to the rake angle α , as it is shown on Fig. 2. So:

$$V_f = \frac{V_r}{\cos(\alpha)} = \frac{1}{2} \cdot \frac{c}{\cos(\alpha)} \cdot \frac{f_d}{f_s} \quad (7)$$

α is the angle between the deflecting direction of radar and the ground, V_r is the radial velocity of radar relative to the ground, V_f is the tractor speed relative to the ground, actually, V_r is the component of V_f on deflecting direction of radar, as is show on Fig. 2.

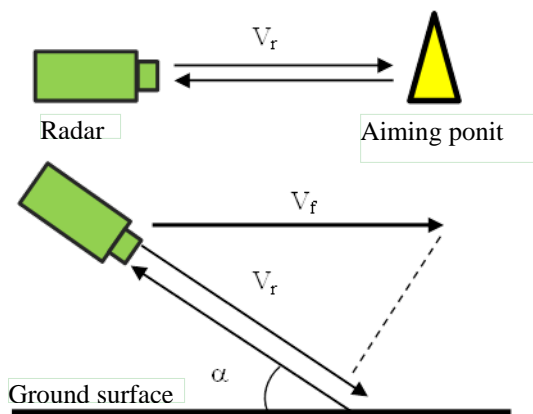


FIG. 2 PRINCIPLE OF OF DOPPLER EFFECT

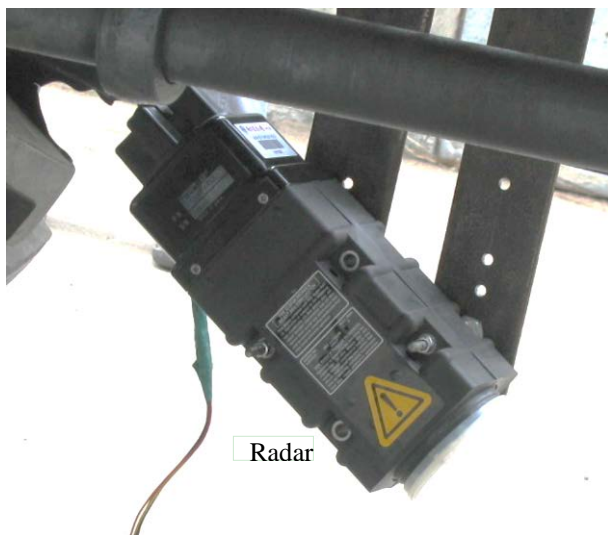


FIG. 3 INSTALLATION METHOD OF RADAR

This measurement chooses Radar II (radar-ground speed sensor) of DICKEY-john Corporation. The velocity range is 0.53-96.6 km/h, true velocity errors is between -5%-5% while the velocity range is 0.53-70.80 km/h, and between -3 % -3% while the velocity range is 3.2-107 km/h. The microwave frequency is 24.125 GHz \pm 50 MHz. It transmit pulse signal and the frequency is f_d . The installation

method of radar-ground speed sensor is shown in Fig. 3. It was installed by a special structure and the rake angle α is 35° .

2) Encoder

As is known, the incremental encoder can provide continuous pluses through its code wheel which runs the following shaft. According to the direction of rotation and the quantity of pulses, angular displacement or rotate speed can be calculated.



FIG. 4 INSTALLATION METHOD OF ENCODER

Omron photoelectric encoder, the model is E6B2-CWZ6C, was chosen in this study. It has three output lines: A, B, Z, which are all pulse signals. Output A and B have phase difference of 90° and all 1000 pulses per revolution, output Z is a zero reference, 1 pulses per revolution. The installation method of encoder is shown in Fig. 4. The axle of encoder was inserted into a coupling mechanism. In the coupling mechanism there is a magnet which can stick to the center of the wheel steadily for it is made of iron. The entire measurement system is shown in Fig. 5.



FIG. 5 MEASUREMENT SYSTEM

1 and 2 – encoders; 3 – radar-ground speed sensor; 4 – pc and daq card

Program Design of the Slip Measurement System Based on LABVIEW

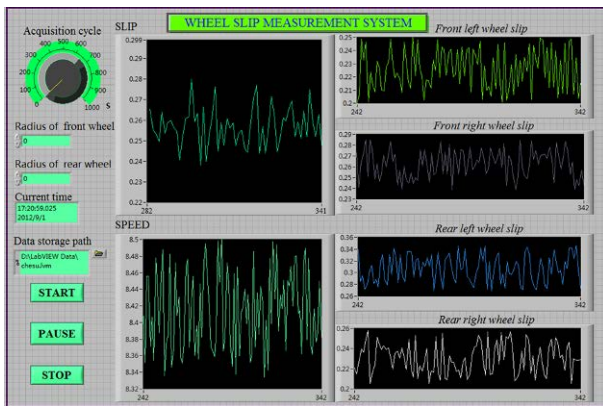


FIG. 6 INTERFACE OF THE MEASUREMENT SYSTEM

A program was design to measure slip based on LabVIEW, Fig. 6 is the interface of this measurement system which can display tractor's slip, speed clearly in real time. Flowchart of the program is shown in the Fig. 7. When the program is running, the DAQ card acquires encoder and radar's pulse signal, and the counter channels can count the quantity of pulses, and sent them to PC. The counters count the numbers of pulses constantly, record them by N_1 , N_2 . N_1 stands for encoder's pulse number; N_2 stands for radar's pulse number. When time $T=1s$, the program calculate the wheel RPM (revolutions per minute) n and tractor speed V based on N_1 , N_2 , after that S can be calculate further. Finally speed V and slip S are displayed on the interface.

Design of Hardware Circuit

According to the operating principle, hardware circuit was designed, as is shown in Fig. 8. It includes: power supply circuit, encoder circuit, radar speed sensor

circuit.

In this study, Advantech PCI-1780 DAQ card was used. It has 16 single-ended/ 8 differential or combination analog input channels and 16-bit resolution A/D converter, with up to 200 kS/s sampling rate, 2 analog output channels, bus-powered.

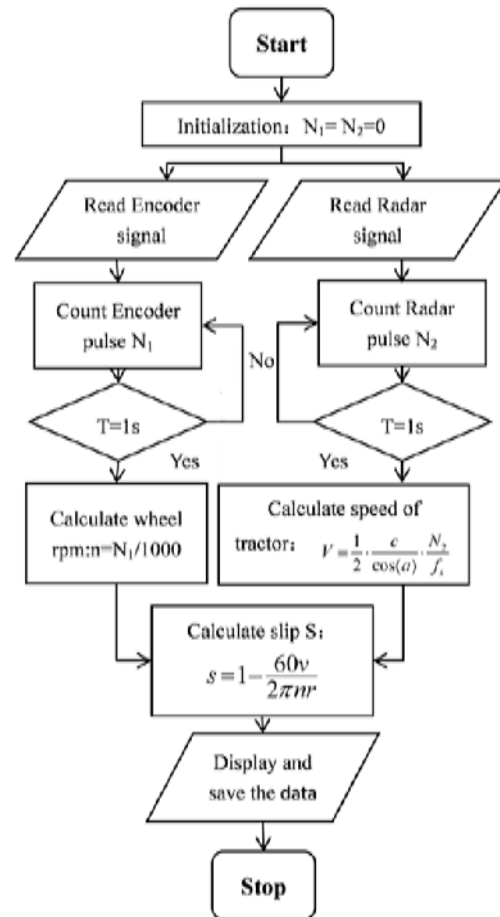


FIG. 7 FLOWCHART OF THE PROGRAM FOR SLIP MEASUREMENT

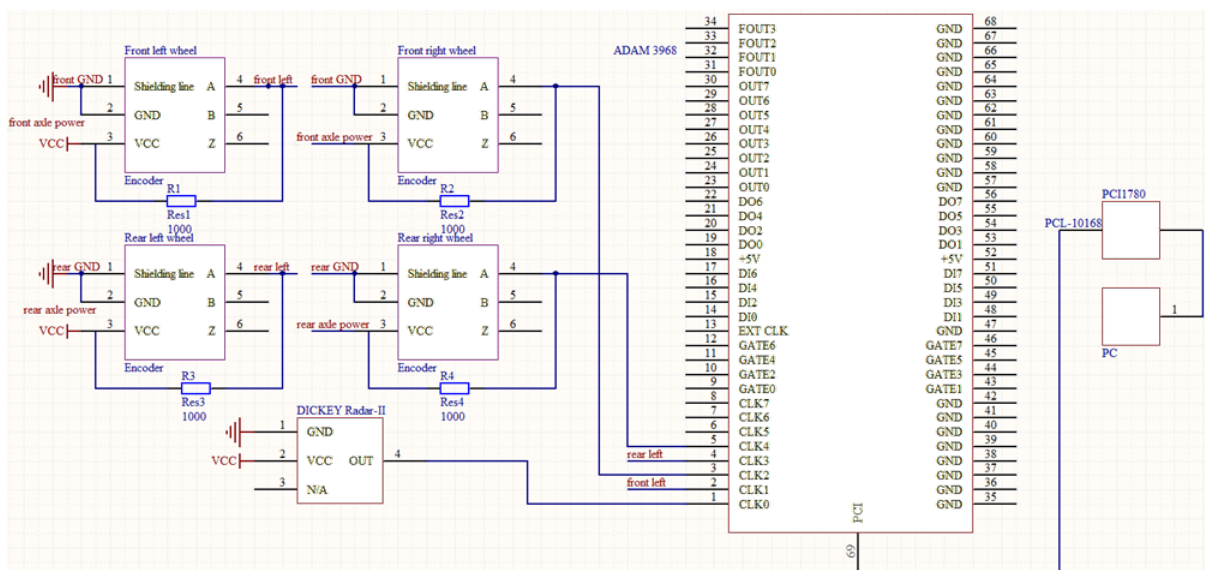


FIG. 8 HARDWARE CIRCUIT OF THE SLIP MEASUREMENT

Measurement and Data Analysis

The purpose of this measurement is to obtain an accurate measurement method of tractor slip, and analyze the slip characteristics of the tractor further. The characteristics contain the change and change rate of slip when the tractor works on different road or at different operating depth, so as to provide a realistic basis for designing intelligent controller. The main experiments designed as follows.

Verification of the Accuracy of Slip Measurement System

Farmland was selected to carry out this test. This test includes three parts: Encoder accuracy verification, Radar accuracy verification, Slip accuracy verification.

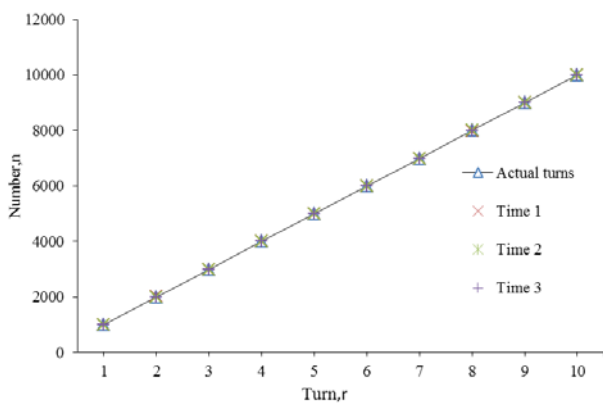


FIG. 9 ENCODER ACCURACY VERIFICATION

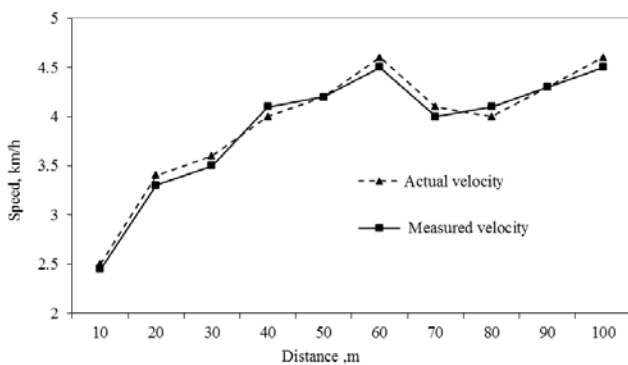


FIG. 10 RADAR ACCURACY VERIFICATION

1) Encoder Accuracy Verification

It is known that this encoder has a resolution ratio of 1000P/R which means that it will send 1000 pulse per rotation. Turn the encoder 1 rotation, 2 rotation...10 rotation, and acquire the pulses using LabVIEW, compare the pulses and the number of turns to calculate the error.

Fig. 9 is the result of this test, it shows that encoder has a good accuracy of measuring RPM, the error is

very small.

2) Encoder Accuracy Verification

The tractor was operated in gear 3 on a 100 meter long test site which was made some marks per 10m, as a result, there are 10 intervals in this test site. When the tractor came across the site, the travel time was recorded per interval. As a result, time and displacement were known, so V_a can be calculated. At the same time measured velocity V_m can be got from LabVIEW, and then compare the error between calculated velocity and measured velocity.

Fig. 10 is the result of Radar accuracy verification test. It shows that the error is about 2%-2.9%, actually, it also can meet the requirements of the system.

3) Encoder Accuracy Verification

On the basis of test 3.1.2, slip accuracy verification can also be carried out. The LabVIEW program recorded the numbers of turns per seconds, and the time per interval, so the numbers of turns per interval can be calculated. And V_a was known, so S_a can be calculated by Eq. (8).

$$S_a = \frac{N_a \cdot 2\pi r / t - 10 / t}{N_a \cdot 2\pi r / t} = \frac{N_a \cdot 2\pi r - 10}{N_a \cdot 2\pi r} \quad (8)$$

Where, N_a is the accumulated value of revolution in one interval, t is used time of one interval.

At the same time, LabVIEW program recorded the S_m per second, and for the travel time per interval is known, the average S_m per interval can also be calculated. Fig. 11 is the result of Slip accuracy verification test, and shows that the error is about 1.5%-2.7% which also can meet the requirements of the system actually.

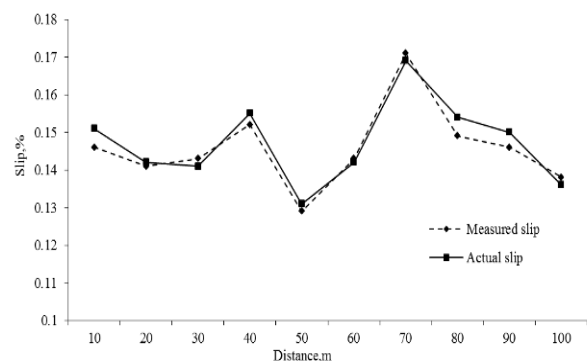


FIG. 11 SLIP MEASUREMENT ACCURACY VERIFICATION



FIG. 12 EXPERIMENT OF SLIP CHARACTERISTICS ON FIELD

Experiment of Slip Characteristics

Similarly, the tractor was operated in gear 2 on the field. In order to analyze the characteristics of the slip completely, the measurement was carried out with different tilling depth (0cm, 10cm, 15cm, and 20cm). Finally, the variation range of slip was analyzed in different load conditions, and then obtained the change and change rate of slip. Fig. 12 is the field experiment.

Fig. 13 to Fig. 16 are the results of slip characteristics experiment. From these Figs, it is observed that:

(1) When the speed of tractor changes suddenly, the slip will shake correspondingly. This state can be found in all of these Figs. Actually, when the speed changes suddenly, especially the tractor is starting or braking, the tractor will vibrate rapidly, at the same time, encoder and radar will vibrate unmorally too, as a result, the slip will shake. In the study, these data were not taken into account.

(2) When the depth is 0cm, the average slip is below 0.1, about 0.03-0.09. When the depth is 5cm, the average slip is about 0.08-0.19, more of these data is around 0.15. When the depth is 15cm, the average slip is about 0.13-0.4, more of these data is around 0.2. When the depth is 20cm, the average slip is about 0.27-0.51, more of these data is around 0.33. It can be finding that the slip become bigger along with the increase of depth.

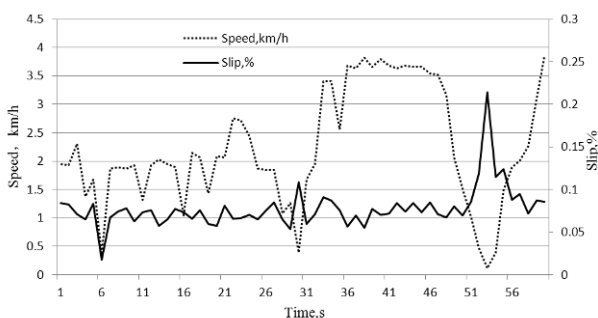


FIG. 13 BEHAVIOR OF SLIP AND SPEED WHEN THE DEPTH IS 0CM

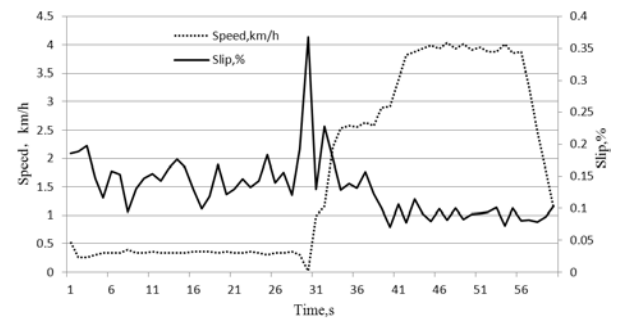


FIG. 14 BEHAVIOR OF SLIP AND SPEED WHEN THE DEPTH IS 10CM

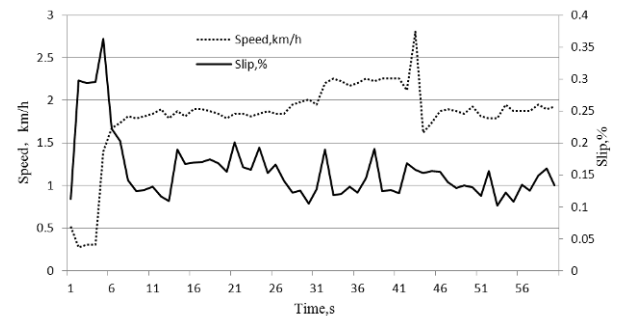


FIG. 15 BEHAVIOR OF SLIP AND SPEED WHEN THE DEPTH IS 15CM

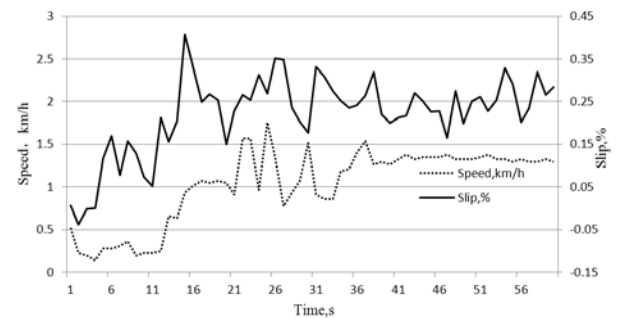


FIG. 16 BEHAVIOR OF SLIP AND SPEED WHEN THE DEPTH IS 20CM

(3) There may has a linear relation between slip and depth, but, it needs more experiments to verify it. Except the time of rapidly change, the speed and slip of tractor are not related.

Conclusion

Based on LabVIEW DAQ system, a digital slip measurement system was developed for 4WD tractor whose error can be controlled in 3%. In contrast to other systems, this system has a high accuracy and it can display the significant signals conveniently, speed, slip, rotate speed, and so on. What is more, some experiments were carried out to measured tractor's slip while ploughing in the farmland, as a result, as the increase of trilling depth, the slip increases too. This slip measurement system can be applied to any make of tractor by changing the appropriate value of rolling

radius via the LabVIEW program. This slip measurement system may also be useful for some research and development works.

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